Status of Sterile Insect Technique Investigations on Codling Moth at the Yakima Agricultural Research Laboratory

U.S. Department of Agriculture
Science and Education Administration
Agricultural Reviews and Manuals • ARM-W-9/July 1979

This publication is available from the Yakima Agricultural Research Laboratory, 3706 West Nob Hill Boulevard, Yakima, Wash. 98902.

International Standard Serial Number 0193-3760

Science and Education Administration, Agricultural Reviews and Manuals, Western Series, No. 9, July 1979

Published by Agricultural Research (Western Region), Science and Education Administration, U.S. Department of Agriculture, Oakland, Calif. 94612

ABSTRACT

Radiation and sterility investigations at the Yakima Agricultural Research Laboratory were begun in 1959. Numerous release programs were conducted from 1964 to 1974, and techniques for rearing, sterilizing, marking, releasing, trapping, and program assessment were developed and refined. Since 1974, research has been directed at biology, behavior, and population dynamics. The result of this research will be applicable in many control programs.

KEYWORDS: Sterile insect technique, sterility principle, codling moth control.

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STATUS OF STERILE INSECT TECHNIQUE INVESTIGATIONS ON CODLING MOTH AT THE YAKIMA AGRICULTURAL RESEARCH LABORATORY

By R. B. Hutt and L. D. White[1]

INTRODUCTION

Baumhover et al. (*1*)[2] reported the control and suppression of screwworm flies, *Cochliomyia hominivorax* (Coquerell), on the island of Curacao, and Knipling (*19*, *20*) theorized on the use of the sterile insect technique (S.I.T.) for control of other pests, including the codling moth, *Laspeyresia pomonella* (L.). Radiation and sterility research on codling moth was begun at the Yakima Agricultural Research Laboratory in 1959. Since then, we have conducted numerous field tests to evaluate and improve the effect of the S.I.T. on wild codling moth populations. This paper appraises past years' research, analyzes various contributions, and reviews the present state of the art.

HISTORY

The first field releases of sterile codling moths were made in field cages in 1963 with moths treated with tepa[3] (Hathaway, unpublished data) or gamma radiation (*8*). In 1963 and 1964, population surveys were made in a 12-acre apple orchard in White Swan, Wash., and in 1964-65 sterile males were released in that orchard (*9*). In 1966-68, releases of irradiated moths were made in two orchards during each year (*4*, *5*, *29*, *31*).

The Wenas Valley program was begun in 1969. Surveys were conducted throughout the valley, and an intensive sanitation program was begun. Rogue trees were removed and destroyed. Thirty-two noncommercial trees were left in the valley. These were either sprayed or had all of their fruit removed. By the end of the 1970 season, the codling moth population was reduced by about 96 percent (*6*). One and one-half million sterilized moths (mixed sexes) were released in the valley in 1971.

The 1970 population was reduced about 92 percent with an estimated overwin-

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[2]Italic numbers in parentheses refer to Literature Cited, p. 8.

[3]Tris(1-aziridinyl)phosphine oxide.

tering population of 595 moths (*7*). In 1972, 1.9 million sterile moths were released in the valley. In the largest acreage of commercial trees in the Wenas Valley, the 322-acre Northwestern Fruit and Produce Co. orchard (approximately 75 percent of the total commercial acreage in the valley), no pesticides were applied and 1.2 million sterile moths were released. Analyses of survey data and counts of infested apples at harvesttime showed a suppressive effect of 63 percent as compared with the infestation expected if no sterile moths had been released. The percentage of infested fruit, however, rose from 0.002 percent in 1971 to 0.129 percent in 1972--a 64-fold increase (*26*).

Three 31-acre plots in the Northwestern Fruit and Produce Co. orchard were used for releases in 1973. Sterile males (210,000) were released in one plot, sterile females (191,800) in another plot, and sterile mixed sexes (375,000) in the third. A fourth 31-acre plot (standard insecticide regimen for codling moth) was used as a control. There was a high degree of suppression in each plot (male only, 86 percent; female only, 87 percent; mixed sex, 89 percent). In 1973, the number of larvae that went into overwintering diapause increased as compared with that in 1972. In the control plot, 99.6 percent of the population (*32*) was suppressed.

No releases were made in 1974.

DISCUSSION AND ANALYSIS

Analysis of the progress in the application of the S.I.T. to codling moth to 1974 gave the following picture: Release of sterile insects alone effected suppression of the population; however, the suppressive effect was not sufficient to prevent an increase in the native population. The release of sterile insects plus the judicious use of pesticides will suffice to hold the native population in check, and the addition of thorough sanitation practices to the S.I.T. greatly enhances the effectiveness of that technique. The release of irradiated mixed sexes seems to result in a greater degree of suppression than does the release of sterile females alone or sterile males alone. Despite the success of the combined release of sterile moths, sanitation, and judicious use of pesticides in suppressing the native population, we felt that the efficacy of the S.I.T. alone could be greater than it was.

No doubt the S.I.T. can effectively suppress a population of codling moths and effect a reduction of the population. In 1971, 168 fertile males and 168 fertile females (laboratory strain) were inadvertently released in the Roger McPherson orchard, a 77-acre codling moth-free planting of red and golden delicious in the Wenas Valley. On each of the two following evenings, about 5,000 sterile males were released in the area surrounding the site of the fertile release. Preharvest inspection and removal of infested fruit and harvest sampling resulted in a calculated infestation that was 42 percent smaller than the infestation we would have predicted from females that had already mated in the laboratory prior to their release (*30*).

After analyzing the data from the 1972 and 1973 release programs, we decided that considerable basic research was necessary before initiating new release programs. The disparity in the results of the releases in the Northwestern Fruit and Produce Co. and Roger McPherson orchards left us with no doubts that

many problems were yet to be solved. In a thorough analysis and assessment of the entire sterility program through the 1973 release season, we considered the advantages and drawbacks of the various YARL release programs.

We felt that the following general requirements must be met in implementing a successful sterile insect release program:

1. Adequate host isolation.
2. Thorough sanitation program.
3. Maintenance of a positive working relationship with involved property owners.
4. Knowledge and on-going monitoring of major immigration routes.
5. Prior knowledge of chronic infestation sites.
6. Understanding of the biology of the native and released insect.
7. Adequate rearing potential to meet release and brood needs.
8. Rearing must be done on artificial diet.
9. Adequate releasing techniques to deliver maximum quantity and quality of moths into the desired areas.
10. Adequate sterilization equipment and technology.
11. Sufficiently vigorous released population to preclude most N x N matings.
12. Effective early warning monitoring system for infestation.
13. Flexibility and potential to implement all integrated techniques required to suppress the population.
14. Ability to objectively and accurately analyze and assess results of the release program.
15. Adequate funding and staffing to meet program needs.
16. Decisions for and implementation of release program must be based on local empirical data and other requirements as determined at the station level.

We determined that more information in several areas of investigation might be of critical importance in significantly increasing the efficiency of and reducing the costs of a release program. The categories and subcategories listed below outline these areas.

1. *Rearing*

    a. Conversion to diet rearing and solution of attendant problems.

    b. Identification and modification of aspects of rearing technology that contribute to attenuation of vigor.

2. *Vigor*

    a. Identification of areas of field performance of reared moths that are impaired by attenuation of vigor.

b. Determination of whether substandard performance is related to rearing or handling procedures and/or irradiation.

c. Linkage of specific technology-related vigor loss to specific aspects of technology (rearing, handling, irradiation).

d. Construction of matrix or index of several simple, rapidly executed tests by which vigor differences can be identified and quantified.

3. *Native Population*

a. Identification, measurement and control or suppression of overwintered population, and impact of this population on first and second brood.

b. Measurement and definition of the intra- and intertree and intra- and extra-orchard movement of males and females.

c. Definition of the effects of terrain, tree canopy, silhouettes, and airmass movement on male and female distribution.

d. Determination and measurement of the effect of population density on moth movement.

e. Relationship and influence of light and temperature as cueing agents for females.

4. *Trapping*

a. Refinement of use of trapping males as an early warning indicator of infestation.

b. Determination of existence or nonexistence of migration routes and strategic trap placement.

c. Determination of relative trap catch efficiency for native and released males.

d. Evaluation and refinement of use of female attractants in the field.

e. Screening of compounds related to known female attractants to find more efficient lures.

f. Development of trapping techniques using low concentrations of pheromone.

5. *Infestation*

a. Development of knowledge of chronic "hotspots" in release orchard.

b. Development of a routine survey system to expose incipient infestations.

c. Improvement of techniques to indicate when, where, and if supplemental controls are needed.

These five categories and their more specific sublistings have been developed as priority areas of research needs because of problems found in previous release programs. Categories 1 and 2, rearing and vigor, must be considered as areas of continuing research as long as moths are reared for release or research.

Although we still rear insects on thinning apples, we are limited to a maximum production of 20,000 moths per day. Beyond that point, the logistics of rearing become so unwieldy as to render rearing on thinning apples impossible. A larger operation would require conversion to artificial diet. Several options are open to us as indicated by Brinton et al. (*3*), Howell (*11*, *12*, *13*), Howell and Clift (*14*) and Hathaway et al. (*10*). We are currently experimenting with dry-mixed, cold gelling diets.

We have been aware of vigor problems in reared moths for many years. In release programs of earlier years, released moths were commonly found in release stations after 2 or 3 days during cold weather. In release-recapture studies in the Northwestern Fruit and Produce Co. orchard in 1976, moths were released into the grass at the base of the trees. When trap collections were made 3 or 4 days later, 50 percent or more of the moths could still be found in the release spot if the weather had been cold. During those and other cold periods when no released moths were trapped, native moths were captured.

Although enormous numbers of males were released in accomplishing the suppressive effect referred to earlier in the McPherson orchard, we feel that it is of greater significance that laboratory-reared males were used against laboratory-reared males and females, and problems of asynchrony of stimuli and response were absent.

Hutt (*15*) reported on the loss of responsiveness by males to synthetic sex pheromone with increasing length of time in colonization and (*16*) on the improvement of field performance through the manipulation of rearing conditions. White et al. (*33*, *34*) reported that varied photophase entrainment in laboratory-reared moths affected the amount of mating.

The debilitating effects of exposure to radiation have been documented for many insects and considerable work in this area has been done at YARL. White and Hutt (*27*) reported on the effects of exposure to gamma radiation on longevity and oviposition and (*28*) reduced light trap catches with exposure to radiation.

Hutt and White (*17*, *18*) reported on using mating propensity to measure loss or enhancement of mating capacity due to exposure to gamma radiation. Further studies have shown that this technique can be used to measure vigor differences between colonies and differences occurring with length of time in colonization (Hutt, unpublished data). Male reproductive potential appears to be a good indicator of the constitutional strength of a strain of moths, and shifts in eclosion curves appear to be correlated with deterioration of field performance (Hutt, unpublished data); however, further investigation is needed in this area. Simple tests and measurements are needed which can be related to rearing, handling, or radiation technology and to field performance to develop a quality control index.

In tests using an aktograph (*2*) to measure activity in a strain of moths colonized in 1973, we found that at 20 generations in colonization the laboratory strain exhibited both evening and morning activity periods as did native moths from the field. By the time 32 generations had been reared in the laboratory, the morning activity period had disappeared (Hutt, unpublished data). This same strain was released in the field at 36 generations of colonization,

and timed recaptures were made throughout the night. Laboratory males were recaptured in each 15-min trapping interval in which native males were captured during the evening activity period; however, no laboratory males were captured during the early morning activity period but native males were caught (Hutt, unpublished).

Hutt (unpublished data) has considerable data showing that irradiated laboratory males do not disperse as far or as fast as do unirradiated laboratory males in release-recapture studies.

The moths used in the Wenas Valley program were colonized in the laboratory in 1959. Some additional native material was added to the colony in the early 1960's, but essentially, the strain had been in colonization for more than 190 generations (12 generations per year) when it was discontinued and was probably vastly different from the native moths. M. D. Proverbs (personal commun.) keeps a colony in the laboratory no more than 2 years before starting a new one. This has undoubtedly contributed to the effectiveness of his release programs in British Columbia.

We have done very little with overwintering populations, although White is currently investigating eclosion profiles and fecundity of overwintering populations.

Hutt is currently investigating (1) moth movement within and without the trees and orchards, (2) effects of external stimuli on moth movement and distribution, (3) light and temperature as cueing agents for female calling attractants and for trapping females, and (4) use of low concentrations of sex pheromone.

Although the technology and mechanics of a sterile insect release program have been improved over the years, further modification and improvements are needed to increase the efficiency of a large-scale program. Suitable techniques for marking (*21*, *22*) and releasing moths (*23*, *25*) are available.

Considerable progress has been made in surveying, sampling, and interpreting trapping data (*26*, *31*, *32*); however, these techniques supply only a small portion of the information about released and native populations necessary to implement a large-scale program.

Knowledge in these areas will provide the groundwork for studying effects of density on moth movements, refinement of trapping techniques, and migratory movements and trap placement. In turn, this knowledge will provide the basis for investigations into the nature and origin of chronic hotspots and the development of survey systems to indicate incipient infestations and the need for supplemental control measures.

White et al. (*26*) reported that in the 1972 Wenas Valley program, the overall weekly ratio of sterile (S) to native (N) males for the entire Northwestern Fruit and Produce Co. orchard ranged from 54:1 to 938:1 per week. Nonetheless, for individual traps at various weeks during the season, the S:N ratio dropped far below the overall ratio. Seventy-eight percent of larval entries developed within 500 ft of those traps which had a ratio of less than 20:1 during any week of the season. The authors present a more realistic analysis of the S:N ratio in one infestation area, calculating that the real ratio in that area was approxi-

mately 5S:1N. This calculation is done on a moth per tree basis and seems to us to be an eminently more accurate means of program planning and assessment than trap ratio measurements.

During the 160-day season of the 1972 Wenas program, each tree in the Northwestern Fruit and Produce Co. orchard received 36 moths. The overall orchard ratio of S:N for the 1972 season was 1745S:1N. The overwintering population prior to the release program was estimated at 4.5 moths per acre, and no control measures of any sort had been taken. An infestation projection of 110,857 entries was estimated for the end of the season. The suppressive effect was estimated at 63 percent. The overwintering population prior to the 1973 release program was estimated at 39.6 moths per acre in the mixed sex plot. In the 1973 release program, each tree received 104 moths and had an overall ratio of 855S:1N (*32*). The suppressive effect was calculated at 89 percent. On a trap ratio basis, the suppressive effect of releases in 1972 should have been considerably greater than in 1973, especially in the light of the lower overwintering population. Actually, as stated above, suppression was far greater in the 1973 releases, and the numbers of moths per tree corroborate this.

Knowledge of codling moth populations has progressed to the point where we recognize that the population of each orchard has unique characteristics and attributes. Intraorchard movement and loci of chronic hotspots differ from one orchard to the next. Therefore, in conducting a release program in an orchard that has not been studied to define population movements and hotspot areas, numbers of moths released should be based on the maximum estimated native population in any one tree. In a well-managed commercial orchard, the majority of the trees have no population; a few trees may have a population of two to eight moths (one to four males). Until the orchard is mapped and chronic hotspots are defined, each tree in the orchard must receive inundative releases as though it were the tree with a population of native moths. Consequently, the number of moths released during the early years of a program must be far greater than called for by early modeling estimates.

Ideally, the peculiarities of population behavior should be worked out for each orchard; however, the enormity of the timespan required to accomplish this task renders it impractical on any basis other than an "as need arises" basis.

CONCLUSIONS

Although the codling moth S.I.T. program as conducted in the Wenas Valley in the early 1970's is not sufficient unto itself, it is available as a workable and useful tool should the need arise in an integrated pest management program. The additional knowledge acquired since that time would undoubtedly increase the effectiveness of another program.

Rearing techniques are of paramount importance when the colonized insect is used for a sterile release program or in field ecology studies. Proverbs (*24*) decries the lack of basic knowledge of biology, behavior, and population dynamics of the codling moth and states that this pest and others "require much more detailed study before the sterility method can be applied intelligently." We have strongly de-emphasized research on the field application of the S.I.T. The

lines of investigation into basic biological and behavioral phenomena and population dynamics now pursued by both authors will yield multiple use results; that is, the results can be used to enhance the efficiency of an S.I.T., pheromone, trapping, chemical, or integrated control program.

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